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THE BENTONITES AND CLOSELY RELATED ROCKS OF PATAGONIA¹

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The present paper records a number of interesting features noted in the study of a suite of rocks collected in Central Patagonia by Dr. G. G. Simpson while leader of the Scarritt Patagonian Expedition. The study is concerned primarily with the petrographic and physical character of the rocks. The suite of rocks is of particular interest, since in addition to features described in this paper it represents geologic formations known to contain fossil mammals of early Tertiary age.²

An outstanding result of this work is the recognition that almost the entire Lower Tertiary of Central Patagonia is bentonitic in character and that much of it is a rather pure bentonite.

Information in regard to stratigraphic and structural relations of the rocks in the field has been obtained from the field notes of Doctor Simpson.

The mammal-bearing rocks of Central Patagonia have been recognized as tuffs and as such are described briefly by María Casanova.³

It is a fact that tuffs, for the most part volcanic ash rather than tuff, do occur in the Lower Tertiary of Patagonia, but they are not the most abundant rock type; by far the greater proportion of the so-called tuffs are really bentonites or rocks intermediate between tuff or volcanic ash and bentonite. It is the presence of considerable amounts of the mineral montmorillonite together with a texture derived from volcanic ash that has led to the identification of such rocks as bentonites.

Considerable research has been done on the physical, chemical and petrographic properties of bentonite by such investigators as Ross, Shannon, Spence, Kerr, and others⁴; the properties are described in the papers cited.

¹Publications of the Scarritt Patagonian Expedition, No. 17.

²Simpson, G. G.—Personal communication.

³Casanova, María. 1931. 'Apuntes petrográficos sobre los terrenos atravesados por los pozos de Comodoro Rivadavia y sus alrededores.' Contribuciones a la primera reunión nacional de geografía, Buenos Aires, Mayo-Junio de 1931, V.

⁴Ross, C. S., and Shannon, G. V. 1926. 'The Minerals of Bentonite and Selected Clays and Their Physical Properties.' Journ. Amer. Ceramic Soc., IX, No. 2, pp. 77-96.

Ross, C. S. 1928. 'Altered Paleozoic Volcanic Materials and their Recognition.' Bull. Amer. Assoc. Pet. Geol., XII, No. 2, pp. 143-164, Feb.

Spence, H. S. 1924. 'Bentonite,' Mines Branch, Dept. of Mines. Ottawa, Canada, No. 626.

Kerr, P. F. 1931. 'Bentonite from Ventura, California.' Econ. Geol., XXVI, pp. 153-168.

Kerr, P. F. 1932. 'Montmorillonite or Smectite as Constituents of Fuller's Earth and Bentonite.' Amer. Mineralogist, XVII, No. 5, May.

Ross and Shannon define bentonite as follows: "Bentonite is a rock composed essentially of a crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash; and it often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass. These are feldspar (commonly orthoclase and oligoclase), biotite, quartz, pyroxene, zircon, and various other minerals typical of volcanic rocks. The characteristic clay-like mineral

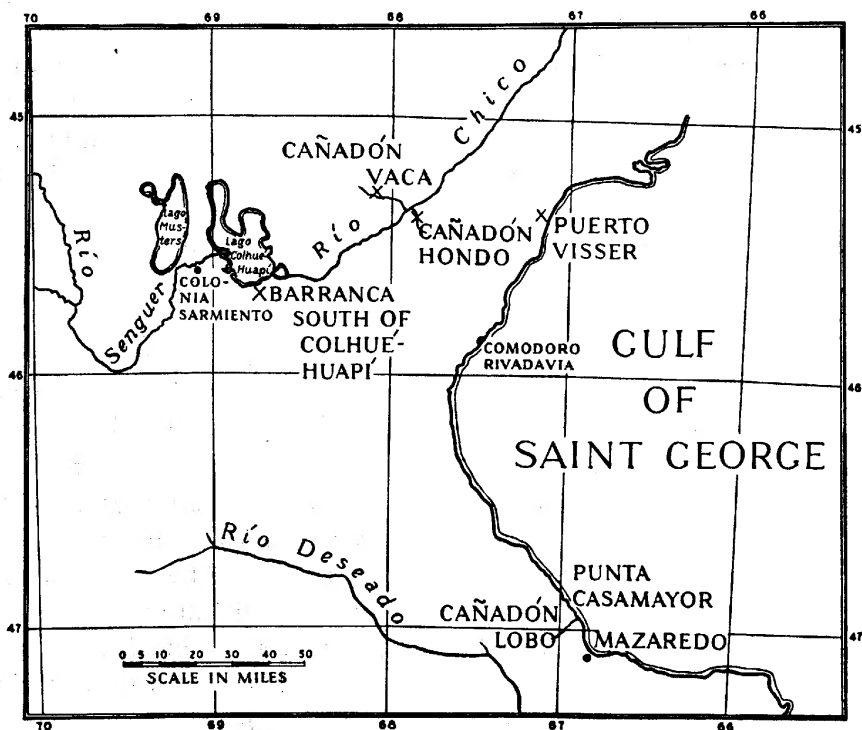


Fig. 1.—Sketch map of central Patagonia, showing the localities mentioned in the text. (After Simpson, previously unpublished.)

has a micaceous habit and facile cleavage, high birefringence and a texture inherited from volcanic tuff or ash, and it is usually the mineral montmorillonite,¹ but less often beidellite.”²

Before giving a detailed description of the bentonites, it seems in order to describe the volcanic ashes, since they are the parent rocks of the bentonites:

¹Montmorillonite was described in 1847 by Damour and Salvétat. 1847. *Ann. Chimie et de Physique*, 3d Series, XXI, p. 376.

²Larsen, E. S., and Wherry, E. J. 1925. 'Beidellite, a New Mineral Name.' *Journ. Wash. Acad. Sci.*, XV, pp. 465-466.

The typical volcanic ash is a rock, light in color, i.e., gray or light brown, medium to fine-grained, often very porous and distinctly gritty to the touch. In thin section the ash is seen to consist almost entirely of irregular-shaped fragments of volcanic glass. The glass fragments are usually angular and show a distinct conchoidal fracture; occasionally a spherical-shaped mass is seen. Such masses represent volcanic glass bubbles. In addition to the volcanic glass there are always a number of fragments of such minerals as feldspar, both orthoclase and plagioclase of albite to andesine composition, and quartz. Usually a few fragments of pyroxene, amphibole, magnetite, epidote, zircon, biotite and chlorite are present.

Some of the ash beds contain geodes which are composed of quartz, banded-chalcedony and opal, while others have tiny veinlets of quartz and chalcedony irregularly distributed through them. The quartz, chalcedony and opal in the form of geodes and veinlets are evidently a secondary product.

The bentonites of Patagonia are typically very clay-like in appearance, and are similar to the ash rocks in color except that yellow and buff color are more predominant. Macroscopic examination reveals at least two and sometimes three rather distinct types. The first is very compact and is smooth or slippery to the touch; the second is more loosely aggregated, i.e., powdery in nature, and is slightly rough to the touch, and the third, though not always distinct from the second, is massive and hard and usually very rough to the touch. An important physical property of some bentonites is to increase in volume very perceptibly when placed in water. Spence¹ records an increase of 13.8 times its original volume when a certain bentonite was allowed to take up all the water it would hold and still retain its form. Many of the Patagonian bentonites illustrate this property of swelling when placed in water. A distinct relationship seems to exist between the type of bentonite and its behavior when placed in water. The compact bentonite swells to many times its original volume when placed in water, and the resultant mass resembles very closely a mass of jelly. In this bentonite the particles tend to hold together even when the bentonite is subjected to great increase in volume, i.e., the mass is more or less coherent in the swollen state. A curious feature of the reaction of this bentonite to water is the fact that in the process of increase in volume, angular fragments of the original dry bentonite fracture and spread apart along lines of intersection of two or more faces of the fragment; each face of the fragment

¹Spence, H. S. 1924. *Idem*—Pl. iv.

then tends to curl or roll into a ball, and finally the entire fragment forms a globular-shaped mass. The powdery type of bentonite behaves very differently in water. It increases in volume considerably but does not maintain or develop definite form; it rapidly disintegrates into small particles and slumps down into the bottom of the container. The third type of bentonite gives no visible physical reaction when placed in water.

The different behavior of the various bentonites is due to the physical condition of the material. The explanation for the rather curious fracturing along acute edges of an angular fragment of the compact bentonite in water seems to lie in the fact that the intersections of faces of the fragment represent the points of greatest stress in the rock consequent upon the sudden great increase in area of each of the faces of the fragment.

The difference in behavior in water of the bentonites is quite distinct, but a similar distinction cannot be made in petrographic study. The petrography of the Patagonian bentonites is very similar to that of the bentonites described by Ross and Shannon.¹

Petrographic examination of a typical bentonite reveals a rock that is, in the main, composed of an aggregation of tiny montmorillonite crystals. In some bentonites the montmorillonite is developed in such quantity that it forms a closely woven network of small crystals; in others, there is a distinct tendency for the montmorillonite to be developed along the borders of fractures in the rock. In addition to the montmorillonite there are always present a few fragments of quartz and feldspar—occasionally orthoclase but more often plagioclase of albite to andesine composition. Ferromagnesian and other high specific gravity minerals are usually present; they are always in very small quantity.

The most common rock type in the Patagonian suites is one intermediate between a volcanic ash and a bentonite. These rocks are seen in thin section to be composed mainly of shards of volcanic glass and of montmorillonite. The glass fragments or shards are usually partially altered to montmorillonite; in such instances the montmorillonite forms a birefringent border zone around the isotropic glass. Often it is possible to note this type of alteration having taken place around a glass bubble; in such instances the montmorillonite crystals are developed like fibres which appear to be wrapped around the glass bubble. Ross and Shannon,¹ in their text figures 1a, 1b, 2a, 2b, show microphotographs of several types of bentonite. Their microphotographs illustrate the Pata-

¹Ross, C. S., and Shannon, G. V. 1926. *Idem*.

¹Ross, C. S., and Shannon, G. V. 1926. *Idem*, pp. 82-83.

gonian bentonites as thoroughly as if they were actual microphotographs of the Patagonian rocks.

Identification of the birefringent material so closely associated with the volcanic glass as montmorillonite was made through refractive index measurements and X-ray analysis. Ross and Shannon,¹ report that "... montmorillonite from normal bentonites has indices of refraction that vary but little from the mean values that are $\alpha=1.493$, β and γ 1.516 and the montmorillonite from other sources shows nearly the same values." The writer finds the montmorillonite of the Patagonian rocks checks very closely in its indices with that given by Ross and Shannon. In all crystals measured, $\alpha=1.49-1.50$ and β and γ very close to a value 1.51. Through the very kind coöperation of Professor P. F. Kerr of Columbia University, X-ray analyses of a few of the bentonite samples were made. Professor Kerr found that certain rock specimens, in which the writer believed montmorillonite did occur, gave X-ray diffraction patterns which agree with those given by members of the montmorillonite group.²

SECTION IN CAÑADÓN VACA

In order to show the genetic relation between the bentonite and the volcanic ash and to emphasize the stratigraphic importance of the bentonite in the early Tertiary of Patagonia, a stratigraphic section in Cañadón Vaca (see Fig. 1) is described in detail. The accompanying diagram (Fig. 2) illustrates the stratigraphic sequence in the *Notostylops* Beds at one point in Cañadón Vaca, and shows by number the positions in the section of the rock specimens described in detail in the following pages. Specimens numbered R41 and R42 are different in field and microscopic appearance from anything seen elsewhere, but these differences prove to be due to the apparently different mode of deposition and to the presence of macroscopic grains or pebbles of volcanic rock, rather than to any marked difference in the essential mineralogic character of the stratum. Except for this one bed, the series is fully typical of the great bulk of the pre-Patagonian³ "tuffs." A large number of mammals of the typical *Notostylops* fauna were found in this section, scattered through it except for the level of R38, which is barren of fossils. They were to some extent concentrated in the strata represented by R45 and R47 and were rarest in the less altered tuffs, e.g., R44, R49.

¹Ross, C. S., and Shannon, G. V. 1926. Idem, p. 96.

²Personal communication.

³For stratigraphic nomenclature and age, see Fig. 4.

Like most of the pre-Patagonian Tertiary exposures, this one consists of beds from one to fifty feet thick, evenly stratified with original horizontality, but generally not sharply limited at their contacts. The rock samples show a minor number of relatively unaltered white to gray volcanic ashes, with a larger amount of true bentonite, and all intergradations between these two extremes. In the field, the purer volcanic ash rocks stand out in recurrent beds because of their whiter color and the fact that they are usually somewhat indurated or concretionary, more resistant to surface weathering. They often form minor scarps, while the bentonites form steep slopes, much checked and weathered, above and below the volcanic ash.

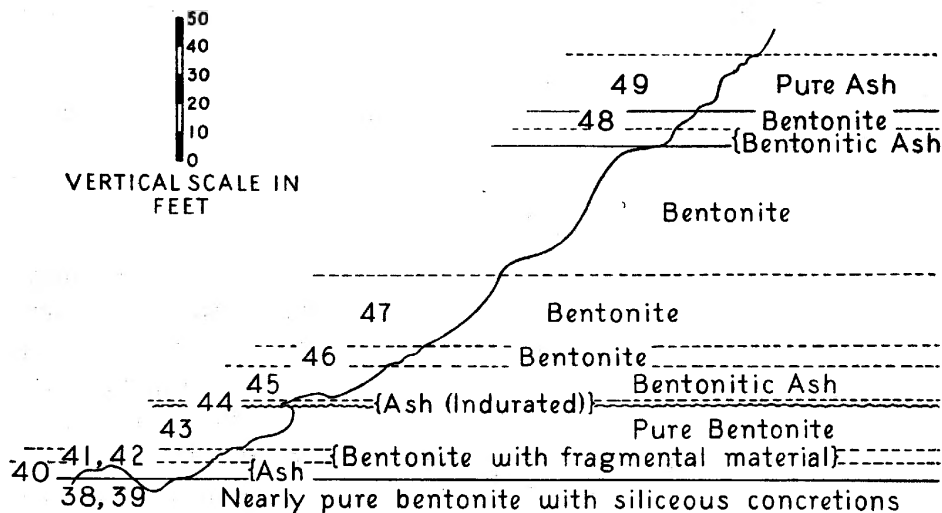


Fig. 2.—Stratigraphic section in the *Notostylops* Beds in Cañadón Vaca. (After Simpson, previously unpublished.)

The relation of the bentonite to the volcanic ash is very interestingly brought out in this and in other sections studied by Simpson in the field but not here given in such detail. They generally alternate, with bentonite much predominant in bulk. The base of a relatively pure volcanic ash usually shows a sharp and somewhat irregular contact, i.e., is disconformable on an erosion surface, probably in most cases representing an inappreciable interval of geologic time, but in some corresponding to a distinct faunal break. The upper contact of the volcanic ash, on the contrary, is usually vague and passes gradually into bentonite.

In some cases fossils are more common in the volcanic ash, but their greatest absolute concentration in the whole formation and their greatest relative concentration in many sections, including the present one, is in the bentonite or in the material transitional from volcanic ash to bentonite. All these facts strongly suggest intermittent heavy falls of ash alternating with periods of weathering and erosion, the latter appar-

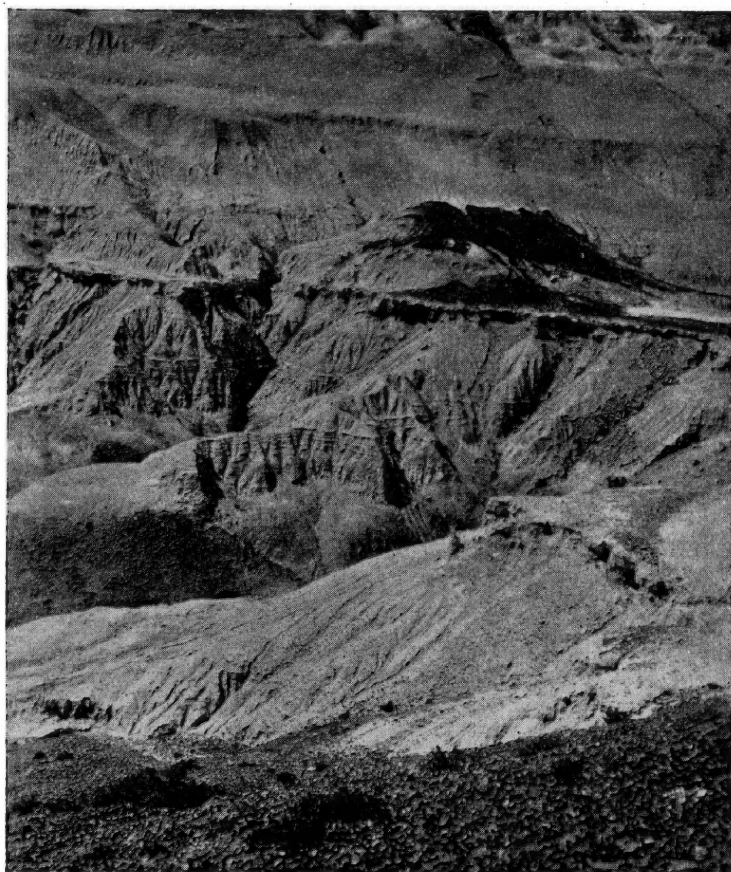


Fig. 3.—View of the Oficina del Diablo, Cañadón Vaca, showing the lower part of the section given in Fig. 2. (After Simpson, *Amer. Mus. Novitates*, No. 566, p. 15.)

The basal clays (bentonites), apparently darker in color, near or below the middle of the left half of the picture, are those represented by R38, and the hard ledge near and somewhat above the middle of the picture is the tuff represented by R44. (The large dark spot in the upper right quarter of the photograph is formed by pebbles which have fallen from the pampa, over three hundred feet above).

ently very slight in most or all cases. The purer volcanic ashes appear to represent the earlier parts of fairly rapid falls of ash, the bentonites the later parts, or slower falls. The bentonite seems thus to be due in large part to contemporary weathering. Concentration of animals in these

beds is then reasonably explained by the fact that these deposits were for a longer time at or near the surface, and that as they weathered and became bentonitic, their sticky character—when wet—would serve to entrap animals and for the rapid engulfing and burial of those that died on them for this or any other reason.

Specimen No. 38—Bentonite

FIELD OBSERVATIONS.—About 100 feet of this material underlies the fossil-bearing beds. It has no apparent bedding and is for the most part gray to cream-colored below the weathered surface, but tends to become more definitely yellowish or reddish on weathering. Concretions are abundant (see No. 39) but no fossils are found.

MACROSCOPIC EXAMINATION.—Specimen is light yellow in color, fine-grained and powdery, swells and disintegrates rapidly into small particles when placed in water.

MICROSCOPIC EXAMINATION.—Montmorillonite is developed in a complete network of tiny fibre-like crystals through the rock. There is very little volcanic glass present and that only in small fragments. There are a number of large acid plagioclase and quartz fragments scattered through the rock.

Specimen No. 39—Concretion

FIELD OBSERVATIONS.—It is a concretion from the same thick stratum as the preceding specimen.

MACROSCOPIC EXAMINATION.—Specimen is a buff-colored, fine-grained concretion rendered quite hard by the introduction of silica. Numerous veinlets and pockets of chalcedony are present through the rock. Quartz and calcite are often associated with chalcedony.

MICROSCOPIC EXAMINATION.—The matrix of the rock is almost all isotropic and has a very low refractive index; it is undoubtedly a form of altered volcanic material but is not a typical bentonitic mineral. There is developed along fractures in the rock a brown-colored mica; it is very similar to montmorillonite and probably belongs to that group. There are many fragments of acid plagioclase and a few of volcanic glass in the rock. Some of the glass fragments form three-pronged individuals; they evidently represent partial sections of three glass bubbles which are in contact.

The rock is a volcanic ash which is partially altered and which is considerably silicified. The presence of siliceous volcanic ash concretions in a bed of bentonite suggests that the silica has hindered the alteration of the ash to bentonite.

Specimens Nos. 40, 44, 49—Volcanic Ash

FIELD OBSERVATIONS.—These represent the less altered volcanic ashes, grayer or whiter in color in the exposures and more resistant to erosion, especially R44 which forms a prominent ledge, in some instances overhanging the bentonite below.

MACROSCOPIC EXAMINATION.—Specimens are white-colored, hard and very gritty to the touch. In some instances the rock is vesicular.

MICROSCOPIC EXAMINATION.—The rocks are for the most part coarse-grained and composed mainly of fragments of volcanic glass. The fragments are usually very clear and almost colorless, but a few are dark in color and clouded with alteration material. Sometimes brown-colored glass fragments occur; they are often filled with gas bubbles. The glass fragments are very angular in shape; three-pronged or Y-

shaped fragments are common. In addition to angular fragments there are round bubble-like globules of glass. Some of the glass fragments are bent and show parallel fracture lines; in such instances some of the contorted fragments become partially anisotropic. The matrix of the glass fragments is a yellowish-brown colored substance which is almost all isotropic. There is also a development of dark green to almost black chloritic material. There is no evidence of development of a highly birefringent mica like that developed in the bentonitic rocks. Throughout the rock there are scattered a few irregularly shaped fragments of quartz and acid plagioclase.

The rock is a volcanic ash, or specifically a rhyolitic ash. A feature of the rock is the extensive development, in some instances, of small round pellets or concretions of volcanic material in a matrix of the same material.

Specimens Nos. 41, 42—Bentonite

FIELD OBSERVATIONS.—Although the particular samples sectioned do not seem to be very distinctive, this stratum in the field is unusual for this formation. Its color is dark gray to greenish gray, more somber than the series as a whole, and it is thin-bedded in contrast to the very massive character of most strata. It has a distinctly sandy feel and appearance and in places contains volcanic pebbles. Although without cross-bedding, it appears to be a stream or shallow water deposit.

MACROSCOPIC EXAMINATION.—These rocks are in general light-colored and fine-grained, but due to inclusions of dark fragmentary material, they sometimes appear dark and coarse-grained.

MICROSCOPIC EXAMINATION.—In thin sections the rock is light brown in color. The fragments of dark volcanic material are opaque. The main constituent of the rock is montmorillonite; the alteration of volcanic glass to montmorillonite is almost complete, with the result that no definite ash structure is visible. Acid feldspar fragments, i.e., both orthoclase and acid plagioclase, are abundant throughout the rock. The presence of this abundant feldspar probably accounts for the sandy appearance of the formation in the field.

Specimen 45—Bentonitic Ash

FIELD OBSERVATIONS.—This is the matrix of the most abundant fossils at this locality. Not only is it richer in mammals than any other stratum or locality known as yet in the *Notostylops* Beds, but it is also unusual in that a number of specimens from it are associated parts of the skeleton, a condition very rare elsewhere. It overlies the hard ledge of R44 and grades into it in a short distance but without a really sharp contact.

MACROSCOPIC EXAMINATION.—Rock is similar in appearance to R44, but it is much finer-grained. There is a rough or ashy feel to the rock but not nearly so pronounced as in R44.

MICROSCOPIC EXAMINATION.—Thin-section study reveals many small round concretions similar to those in R44. Volcanic glass fragments are fairly common but are not nearly as abundant as in R44. Montmorillonite is developed as a network of small crystals throughout the rock. Quartz and acid plagioclase fragments are common.

Specimens R46 and 47—Bentonite

FIELD OBSERVATION.—These rocks appear to represent the still further breaking down of the original volcanic ash overlying and grading imperceptibly into R45.

MACROSCOPIC EXAMINATION.—Rock is light-colored and fine-grained. The ashy character of R45 is not usually perceptible.

MICROSCOPIC EXAMINATION.—There is an extensive development of montmorillonite. Alteration of volcanic glass is almost complete, with the result that almost no glass structure remains. There are angular fragments of acid plagioclase, albite and quartz throughout the rock.

Specimens R43 and 48—Bentonite

FIELD OBSERVATIONS.—In general these specimens represent horizons in which the alteration from volcanic ash to bentonite is complete. Note: R43 and R48, like R38, are immediately overlain by typical volcanic ash beds.

MACROSCOPIC EXAMINATION.—These are very fine-grained and very light-colored rocks.

MICROSCOPIC EXAMINATION.—Petrographic study reveals the rocks to be homogeneous in grain size and composed almost entirely of the one mineral, montmorillonite. The crystals of montmorillonite are needle-like in appearance and have no definite orientation. Fragments of quartz and acid plagioclase are present in both specimens; they are more numerous and larger in R43 than in R48.

Specimen No. 51—Concretion

FIELD OBSERVATIONS.—This is not in the same vertical section as the preceding series, but is nearby and of the same age as the upper part of the latter. It is characteristic of concretionary zones commonly occurring at one or more levels in the *Notostylops* Beds. This particular bed is about eight feet thick and consists of yellow bentonite with very numerous round black concretions, of the size of a pea to that of a walnut. The bed is purely local and cannot be traced more than a few hundred feet.

MACROSCOPIC EXAMINATION.—Specimens are round concretions of very dark, fine-grained material. The dark color, almost black, of the concretions is due to the presence of a manganese mineral which is probably pyrolusite.

MICROSCOPIC EXAMINATION.—The concretions show concentric structure. A large part of the concretion is made up of pyrolusite. There is present in the concretions a small amount of montmorillonite. It is concentrated in concentric zones in the concretions.

A summary of the rock descriptions given shows that in the stratigraphic section illustrated in figures 2 and 3 there is the following sequence of rock types:

R49—Volcanic Ash

R48—Pure¹ bentonite

R46 and 47—Bentonite, contains very few remnants of ash structure

R45—Bentonite with ash structure fairly common

R44—Volcanic ash

R43—Pure¹ bentonite

R41 and 42—Bentonite, contains fragments of volcanic material but no definite ash structure

R40—Volcanic ash

R38 and 39—Nearly pure bentonite, contains concretions at certain levels

¹Pure bentonite is a descriptive term used to indicate a rock in which all remnants of ash structure are gone and one composed of montmorillonite to the exclusion of all other minerals except odd fragments of feldspar, quartz and heavy minerals.

This sequence of rocks indicates rather clearly that the bentonite is a product of the alteration of volcanic ash, since every horizon of volcanic ash grades upward into a horizon of bentonite in which there is abundant evidence of ash structure and of volcanic glass altering to montmorillonite, and this in turn grades upward into a horizon of bentonite in which all evidence of ash structure is destroyed and the rock is composed almost entirely of montmorillonite. The evidence supporting this origin for the bentonite is further strengthened by the fact that the bentonite contains the same variety and quantity of minerals such as quartz, feldspar, and heavy accessory minerals as the volcanic ash.

An additional fact that is clearly brought out in the sequence is the gradational character of the contact between volcanic ash and bentonite on the upper side of an ash bed, whereas in contrast the ash bed itself rests on bentonite with no gradational relation.

SECTION SOUTH OF LAGO COLHUÉ-HUAPÍ

The classic section in the great barranca south of Lake Colhué-Huapí—see Figure 1—has continuous exposures with *Notostylops*, *Astraponotus*, *Pyrotherium* and *Colpodon* Beds superposed (see Fig. 4). The general character of these rocks is similar to that of the shorter and more detailed section in Cañadón Vaca already given, but a few further notes on particular samples from this section are given.

Specimen No. R11—Basalt

FIELD OBSERVATION.—In this area the lava flows are by no means continuous, but appear as lenses in the section, apparently representing tongues of lava filling shallow valleys.

MACROSCOPIC EXAMINATION.—Rock is a medium-grained, weathered igneous rock; it is vesicular with clayey material filling the vesicles.

MICROSCOPIC EXAMINATION.—Rock is felsitic in texture with occasionally an ophitic relation between feldspar and pyroxene. It is composed almost entirely of basic plagioclase feldspar, augite, brown mica and brown hornblende. The feldspars are lath-shaped and are plagioclase of labradorite composition. Augite is present in euhedral crystals and in forms without definite crystal shape. Hornblende is present in small quantity in the form of basaltic hornblende. There is considerable brown mica present.

The rock is an auganite or as more commonly stated a basalt.

Specimen No. R12—Bentonite

FIELD OBSERVATION.—This rock has the characteristic field appearance of a typical bentonite, like those of Cañadón Vaca, but is here of special interest as it intervenes between the extrusive basic rock and the immediately overlying hardened but less bentonitic scarp formed by rocks like the next one described—R27.

MACROSCOPIC EXAMINATION.—Rock is very fine-grained, compact with slippery feel, light brownish-yellow color. It is a typical bentonite.

MICROSCOPIC EXAMINATION.—Thin section study shows the rock to be made up of very tiny crystals of montmorillonite; the crystals have no definite orientation; there is a marked tendency for more extensive development of montmorillonite along the borders of fracture in the rock. The fracture network of the rock is quite extensive. There is at least one prominent band in the specimen in which extensive development of large crystal aggregates of montmorillonite have taken place; it evidently represents an original large fracture along which the alteration of the original rock to bentonite was best able to proceed. There is present throughout the rock a sufficient number of irregular-shaped fragments of volcanic glass and of glass partially altered to montmorillonite to show that the rock was originally a volcanic ash. A very few acid feldspar and quartz fragments are present.

NOTE:—Professor Kerr finds that the X-ray diffraction patterns of a sample of this material agree with those given by members of the montmorillonite group.

Specimen No. R27—Volcanic ash

FIELD OBSERVATIONS.—This is typical of the rock frequently occurring in Lower Tertiary sections in Patagonia and by Ameghino called “tosquilla.” It is gray when unweathered, but often becomes yellow to orange on weathered surfaces. It may be very hard and is usually strongly resistant to weathering, so that it forms benches and vertical or even overhanging scarps. It is very porous and highly vesicular on weathered surfaces. In places it appears to be largely composed of rolled volcanic ash balls, in others to be concretionary, but these two conditions are not easily distinguished. It often contains fossils, but these are sparsely scattered through it and usually rolled and very incomplete. This specimen is from the thickest “tosquilla” series of this section, at and below the base of the *Colpodon* Beds, but other thinner beds of identical nature occur at lower levels in the same section and they may occur at any Lower Tertiary horizon. In some cases they grade laterally into ordinary gray volcanic ash.

MACROSCOPIC EXAMINATION.—It is a hard ash rock, very rough and gritty to the touch.

MICROSCOPIC EXAMINATION.—Rock is composed largely of fragments of volcanic glass. The fragments are very irregular in shape; some exhibit good conchoidal fracture, and they are evidently broken glass bubbles. In some instances the glass fragments grade over into the light-brown colored micaceous mineral montmorillonite. This development of montmorillonite is very insignificant in amount, and consequently the rock exhibits none of the characters of bentonite in the hand specimens. A few fragments of acid plagioclase and quartz are present.

Rock is a volcanic ash and is similar to the other volcanic ash rocks described in this paper.

Specimens Nos. R21—R29—R32—Concretions

FIELD OBSERVATIONS.—These represent two types of concretions very abundant in the Tertiary tuffs. All are from the same great exposure south of Lago Colhué-

Huapi. Locally concretions may characterize a given horizon, but considering the central Patagonian formations as a whole, they may be of almost any age. R21 and R32 are characteristic of layers of spherical concretions, often in the "tosquilla" (R27) or other relatively unaltered volcanic ash, to which they may give the appearance of a conglomerate. They are nearly always spherical and in numerous cases have a small round depression on one side, like the stem attachment of a fruit. R29 is typical of the common siliceous concretions, present in great number and variety.

MACROSCOPIC EXAMINATION.—R21 and R32 are concretions of light-brown colored, very hard volcanic material; they are spherical in shape and are hollow; they have a rather crude concentric structure, i.e., they tend to break apart like a shell from a nut. The concretions range in size from $\frac{1}{8}$ " in diameter to $1\frac{1}{2}$ ". Silicification of the concretions has made them quite hard.

R29 is a geode rather than a concretion; it is composed of chalcedony, quartz, and opal.

MICROSCOPIC EXAMINATION.—R21 and R32 are very dark brown in color in the thin section and transmit very little light. The rock is composed mainly of fragments of volcanic glass. The fragments vary greatly in size and shape; there is, however, a tendency for a concentration of round glass bubbles toward the inside of the concretion. The outer rim of each glass bubble is altered to brown-colored montmorillonite. Small angular fragments of quartz and feldspar are scattered throughout the rock. Most of the matrix of the glass fragments is a dirty-brown isotropic volcanic material—this is especially true of the outer part of the concretion; the inner part, close to the hollow center, has a matrix of montmorillonite. An interesting feature of the concretions is the fact that the central zone gives a rapid swelling reaction when placed in water, whereas the outer zone does not. This feature is evidently due to the presence of montmorillonite in the interior of the concretions and to its absence in the outer part. The fact that the montmorillonite is developed in the interior of the concretion rather than at the exterior seems difficult to explain, especially in view of the fact that in this study it is usual to find volcanic ash grading upward into bentonite. It may be that the outer zones of the concretions represent material added since the alteration on the inside took place, or as in the case of other concretions—e.g., R39—described in this paper, the alteration of volcanic glass to montmorillonite is probably hindered by the introduction of silica, and since the outer zones of the concretions are more silicified than the inner, they are the least altered to montmorillonite.

R29. Thin section of a geode shows the presence of quartz, chalcedony and opal. Quartz crystals radiate from a common point to form a circular mass; these in turn pass into finely crystallized quartz or into radiating chalcedony fibers. Every quartz grain seems to serve as a nucleus for chalcedony. The chalcedony makes up over one-half of the rock. Scattered through the rock are both large and small masses of opal.

The interior of the geode is lined with tiny stalactites of quartz surrounded by chalcedony.

COMMERCIAL ASPECT OF THE BENTONITE

There is available a tremendous supply of bentonite in this region, enough to supply any conceivable world market for centuries. A large

amount is within short wagon-haul of sea transportation at or near Comodoro Rivadavia (see Fig. 1) and a still greater amount along the railway to Colonia Sarmiento. Even Comodoro, however, is so far from any important present or probable future market that this makes much commercial development improbable. A limited amount can no doubt be used in local oil refineries, but this can hardly assume the proportions of an independent industry.

LATER TERTIARY AND QUATERNARY
(here relatively unimportant)

Patagoniano-Marine, probably late Oligocene or Miocene

Terrestrial Tuffs, with at least four distinct mammalian faunas of Tertiary aspect.

Colpodon beds (perhaps in part equivalent to the lower Patagoniano).

Pyrotherium beds

Astraponotus beds

Notostylops beds

"Argiles fissilaires," local, non-fossiliferous, of doubtful age and relationships

Chiefly sandstones and clays, not subdivided by previous work. The "Pehuenche" or "upper beds with dinosaurs" of most recent authors, not the Pehuenche of Ameghino in this region.

Salamanqueano-Marine, probably Senonian, surely Cretaceous.

Very thick and varied continental deposits, the Chubutiano of some recent authors, variously but not yet definitively subdivided. Containing dinosaurs and partly or wholly Cretaceous.

Fig. 4.—Preliminary table of the late Cretaceous and early Tertiary formations of central Patagonia. (After Simpson, Amer. Mus. Novitates, No. 566, p. 4.)

NOTE ON GLAUCONITE ABOVE THE SALAMANQUEANO

The accompanying diagram (Fig. 4) will help to make clear the stratigraphic sequence involved in the preceding sections. The bearing of these petrologic notes on the general stratigraphic problems is to some extent suggested here and will be further discussed in forthcoming work

by Simpson. The present author also plans a later study of the petrology of the so-called "argiles fissilaires," which constitute one of the most puzzling features of Patagonian stratigraphy. Although they do not relate directly to the bentonitic rocks, there are here added observations on a discovery of considerable interest made in the course of the present study.

In central Patagonia the only surely recognized Mesozoic marine formation is the Salamanqueano, apparently of Senonian age. This invasion came from the east and is represented by a wedge of rocks, thick near the coast and thinning out and tending to lose its marine character to the westward. Without going into more stratigraphic detail here, the upper part of this marine formation is usually represented by the so-called Banco Verde, a glauconitic sand of marine to estuarine origin. Above this there is usually a black clay, the so-called guide horizon or Banco Negro, in part of transitional character but generally accepted as the base of a continental late Cretaceous series. Above this is a series of sands and clays, generally but (according to Simpson) erroneously called Pehuenche. The upper part of this series is of Tertiary age. The lower part is probably in places really late Cretaceous, although the lithologic resemblance makes the contact difficult or impossible to establish in most instances.

An unexpected result of this petrographic study is the recognition of glauconitic sandstones in this so-called Pehuenche, well above the Banco Verde and Banco Negro, but still below the known Tertiary mammal-bearing horizons. The most important instance is that of the round hill northwest of Puerto Visser (see Fig. 1); there glauconitic sandstone occurs 45' above the Banco Verde, about 30' above the Banco Negro, and 75'-80' below the lowest Tertiary mammals. The evidence suggests that marine and semi-marine conditions continued here longer than has previously been supposed and that there is a still undefined transitional late Cretaceous division here between the accepted Salamanqueano and the mammal-bearing sandstones of the so-called "Pehuenche." Secondary derivation of the glauconite from the Banco Verde is possible, but appears improbable.

Specimen No. R110

FIELD OBSERVATION.—See above.

MACROSCOPIC EXAMINATION.—Rock is a green-colored soft sandstone. It is homogeneous without evidence of good bedding.

MICROSCOPIC EXAMINATION.—In thin section, the green mineral which gives the rock its color is recognized as glauconite. The mineral is present in well rounded

grains. The cementing medium of the glauconite grains is a light-brown colored mineral, probably some form of altered glauconite. The brown material is almost entirely isotropic. The glauconite grains are typically deep green in color and are almost isotropic. Scattered throughout the rock are numerous irregular-shaped fragments of quartz and feldspar; the feldspar is a plagioclase of labradorite composition.

Another instance, less important because the stratigraphic sequence is not positively established, is of a green sandstone in Cañadón Hondo (see Fig. 1), quite evidently higher than the recognized Salamanqueano and in the so-called Pehuenche. Its relationship to the mammal-bearing sandstones of Cañadón Hondo is not clear, but it is probably somewhat older.

Specimen No. R68

FIELD OBSERVATIONS.—See above.

MACROSCOPIC EXAMINATION.—Rock is a pale-green colored, fairly coarse sandstone which is cemented with calcium carbonate.

MICROSCOPIC EXAMINATION.—The sandstone is composed of detrital grains of glauconite, quartz and feldspar. Calcite is the cementing medium, and it is the most abundant constituent of the sandstone. The green color of the rock is due to the presence of glauconite. The glauconite is present in deep green rounded grains and green and brown irregular-shaped grains.